Simulation framework and case study for the design and optimisation of a combined renewable electricity and heating system with battery and thermal energy storage

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Simulation framework and case study for the design and optimisation of a combined renewable electricity and heating system with battery and thermal energy storage

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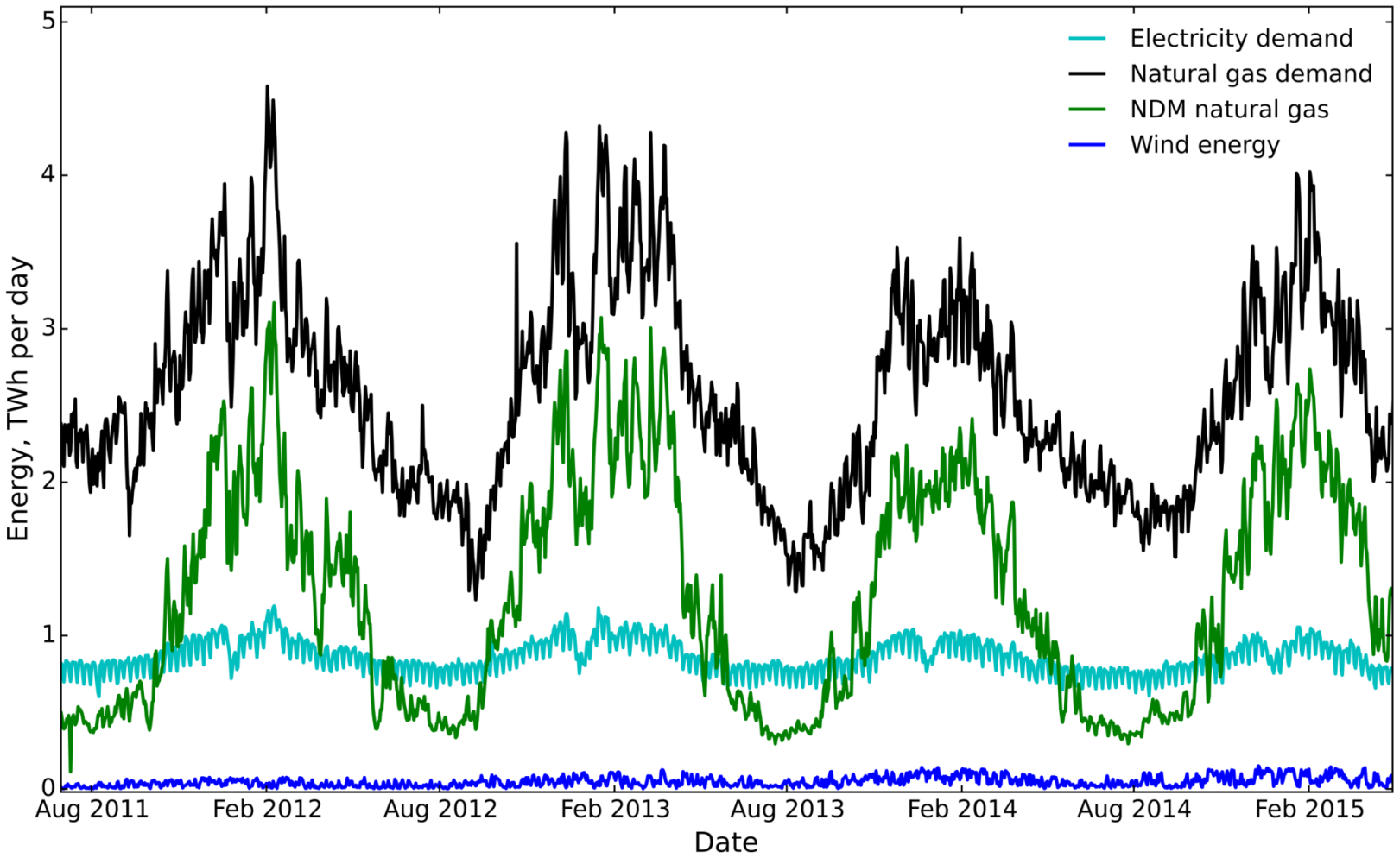
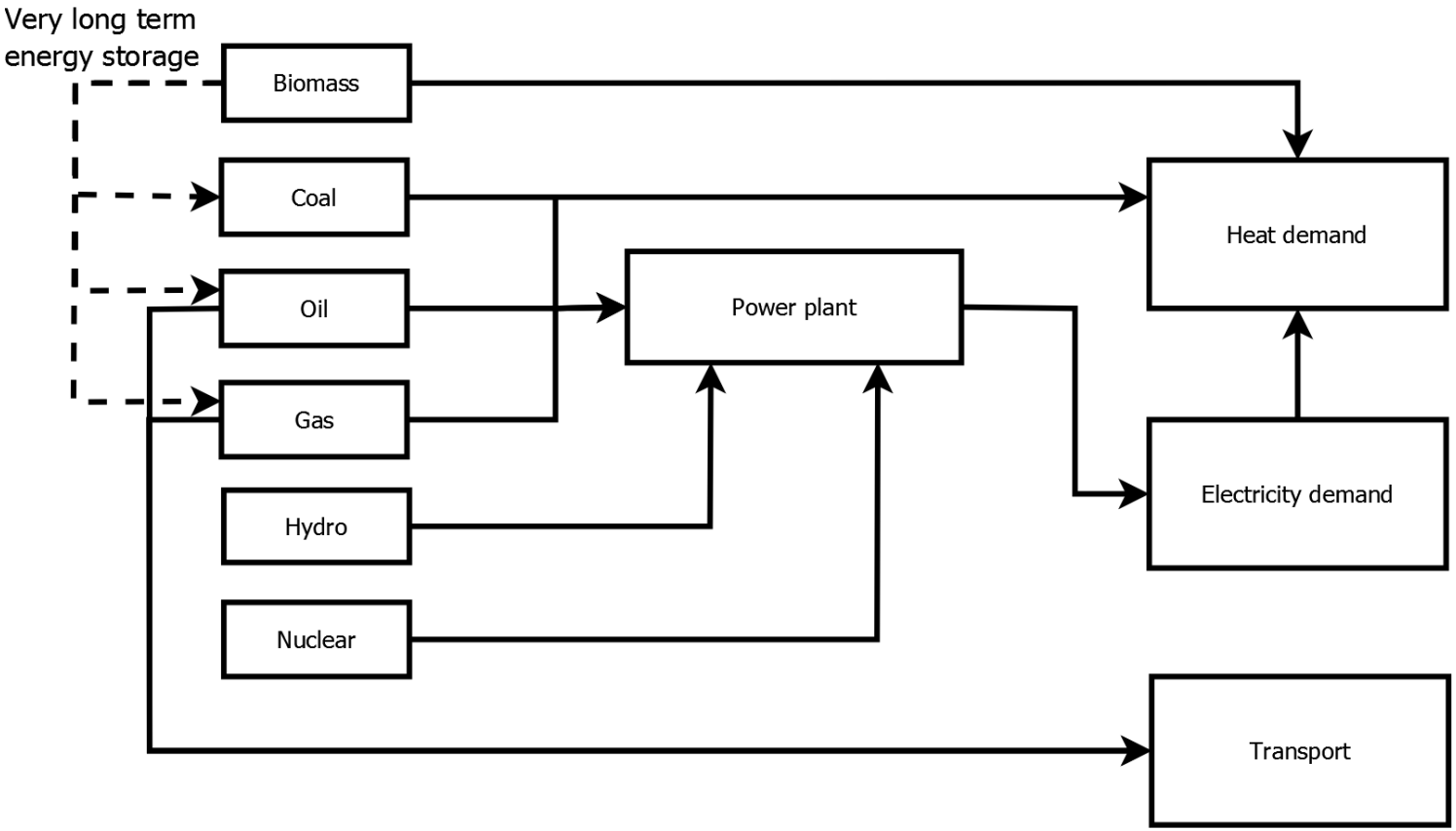
The case for combining heating and electricity



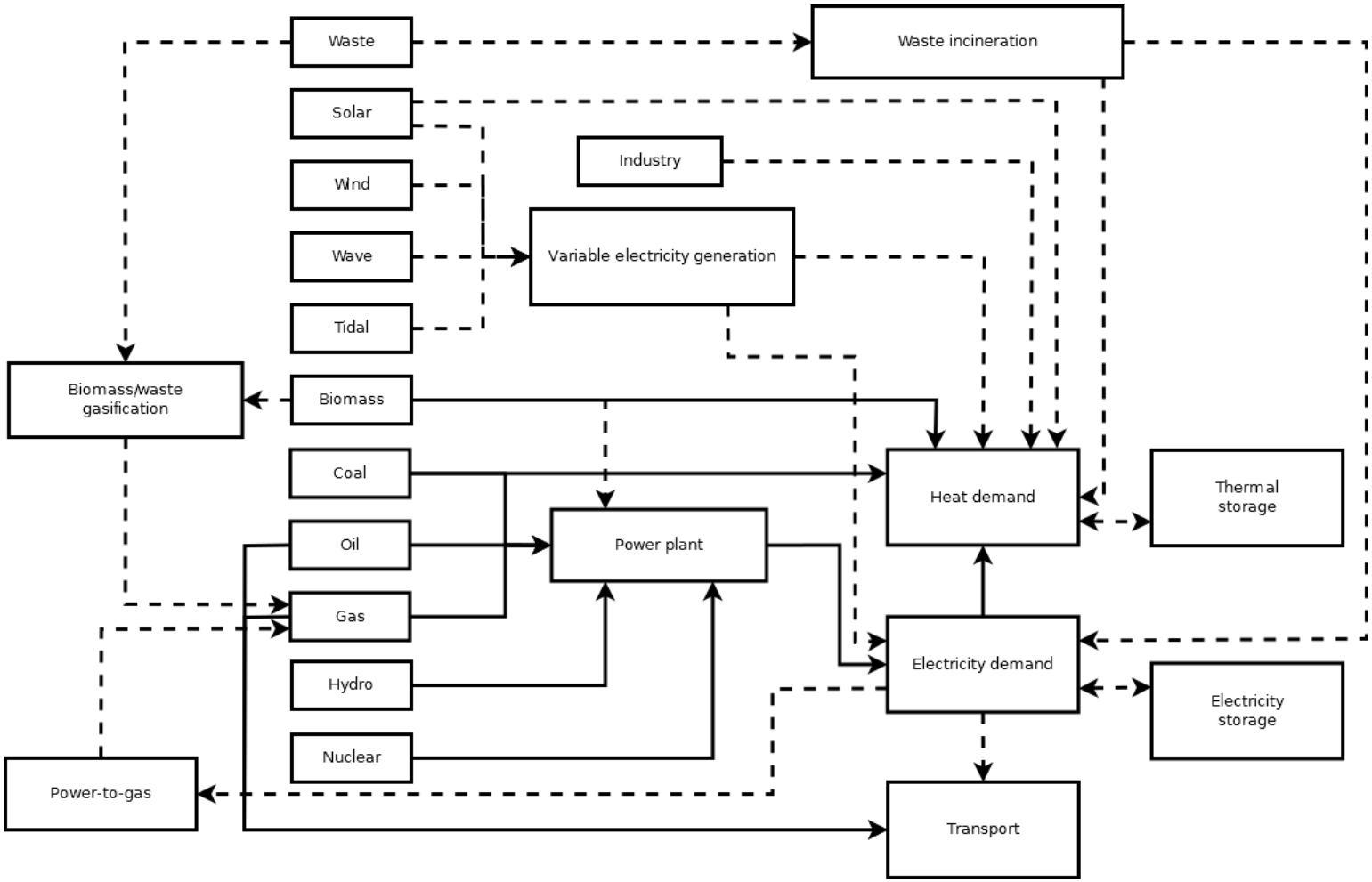
Data from National Grid and http://www.gridwatch.templar.co.uk

Conventional energy system



- Dispatchable generation supplies flexibility to match electricity/heat demand and supply
- Little interaction between heat and electricity systems

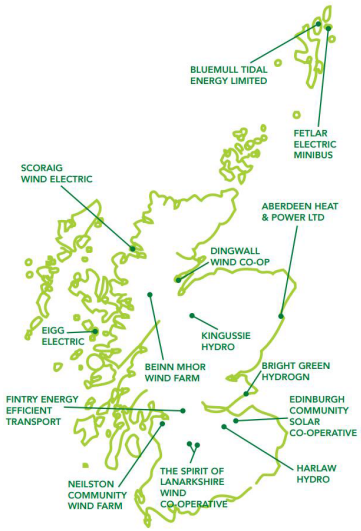
Integrated energy system



1. Add storage, electricity and heat, to provide flexibility
2. Combine different demands and supplies to reduce variation

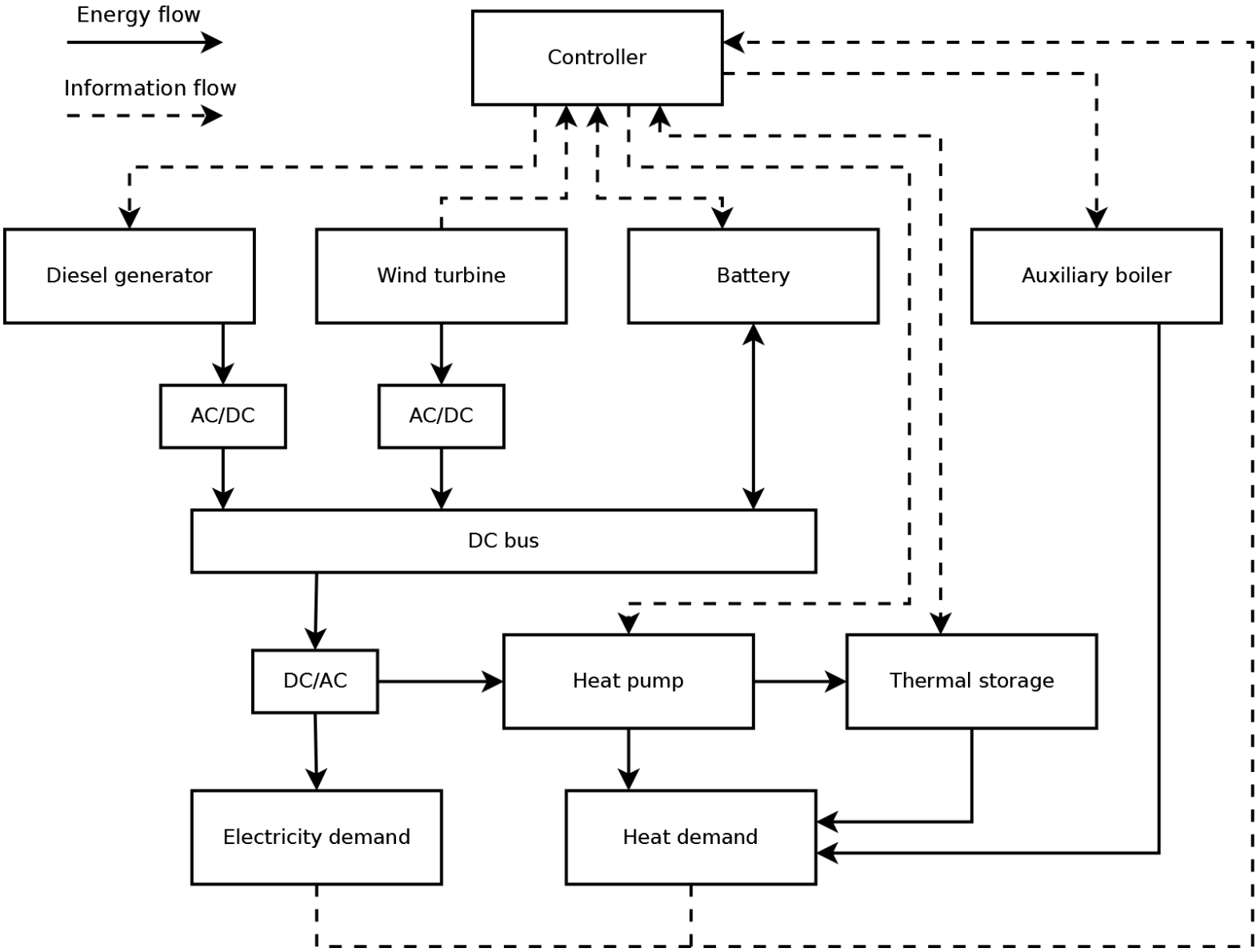
Energy system for remote locations

- Diesel generators provide electricity in many remote locations
- Heat and hot water is generated by gas, oil or biomass boilers
- Dependency on imported and expensive fossil fuels
  - high energy, i.e. electricity and heat, prices
  - emissions of greenhouse gases
- Hybrid energy systems can actively contribute to the reduction of local imports



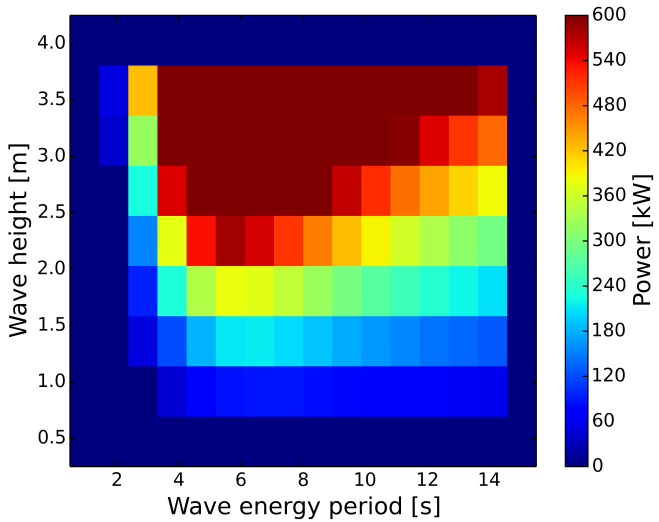
From Remote Islands Grids to Urban Solar Co-Operatives: Community power Scotland, Friends of the Earth Scotland, 2014.

HEATS: Hybrid Electricity And Thermal System



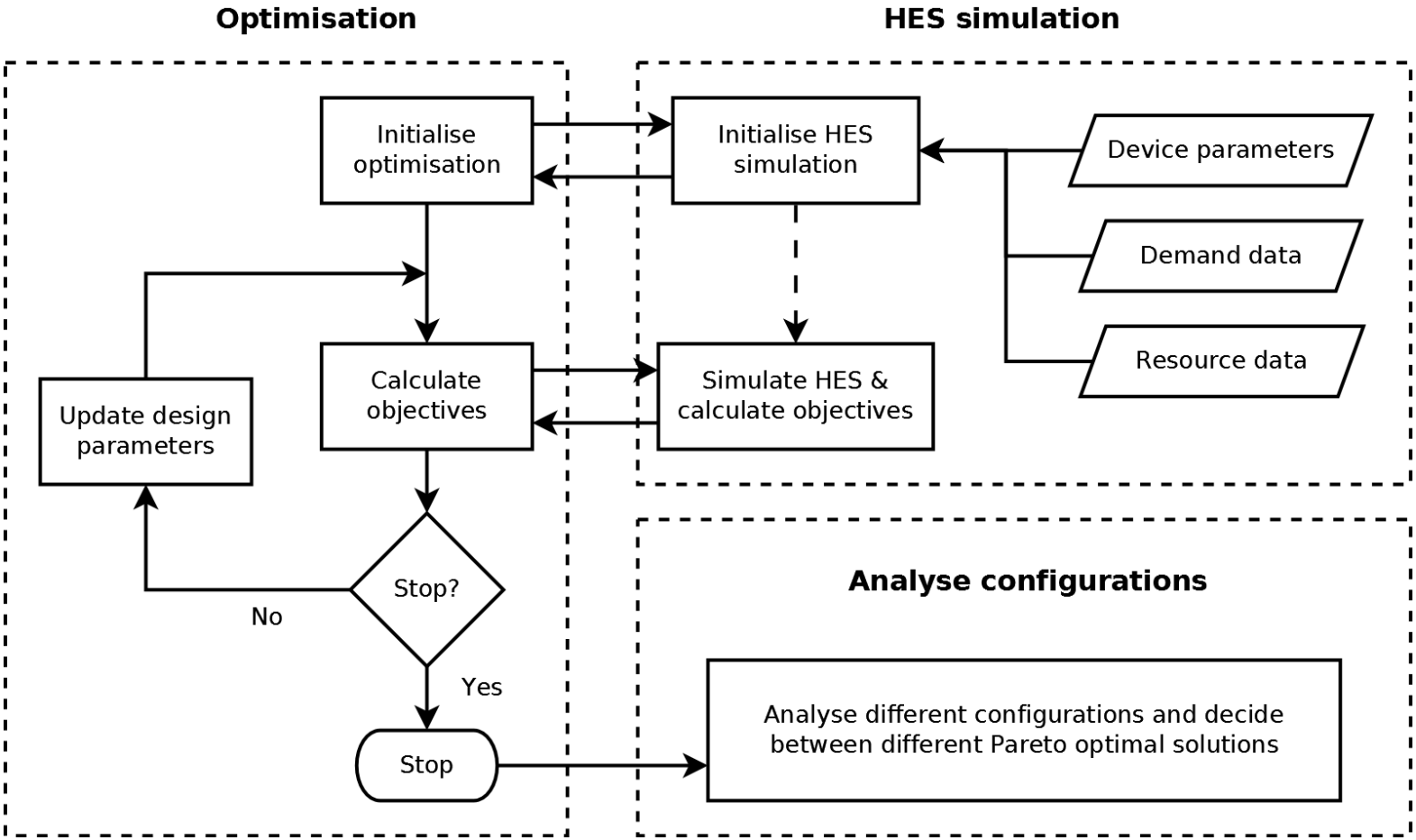
Why not Homer?

- Focused on hybrid electricity systems
  - Limited options to include heat pumps and thermal energy storage
- No multi-objective optimisation
- No wave energy converter



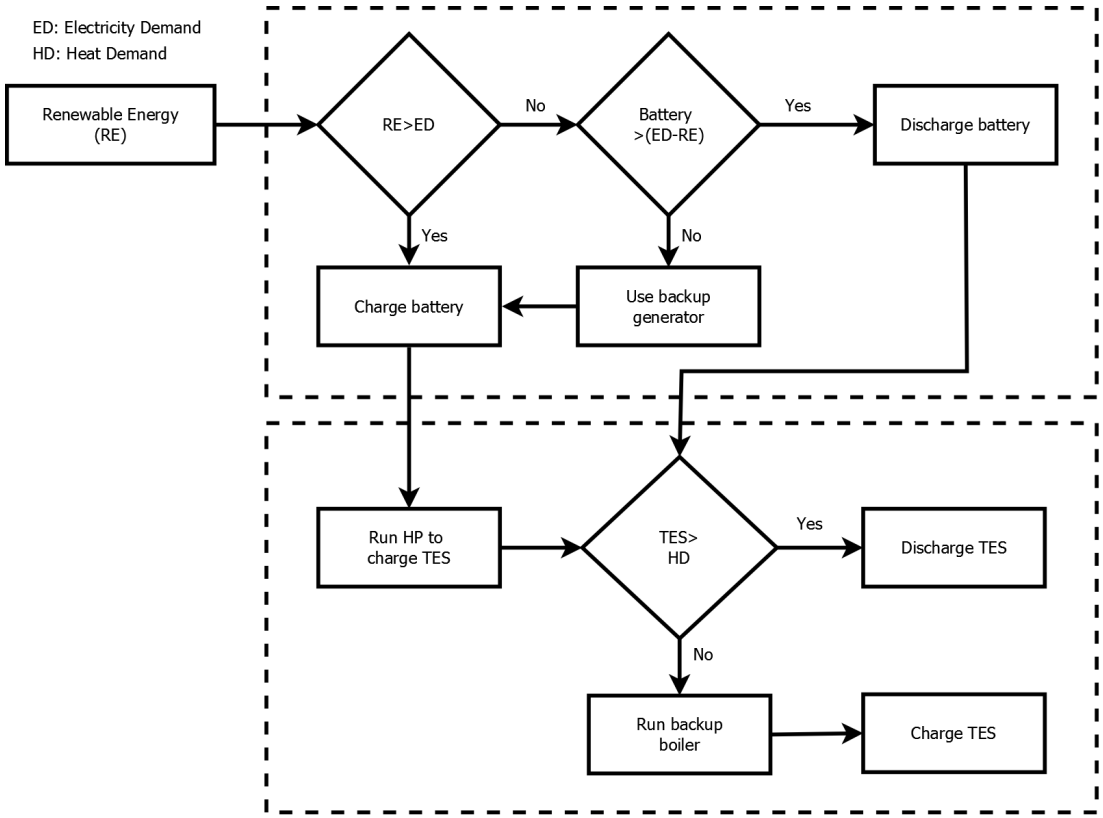
L. Marquis et al, Introduction of Wavestar Wave Energy Converters at the Danish offshore wind power plant Horns Rev 2, 4th Int. Conf. Ocean Energy, 2011

Optimisation framework



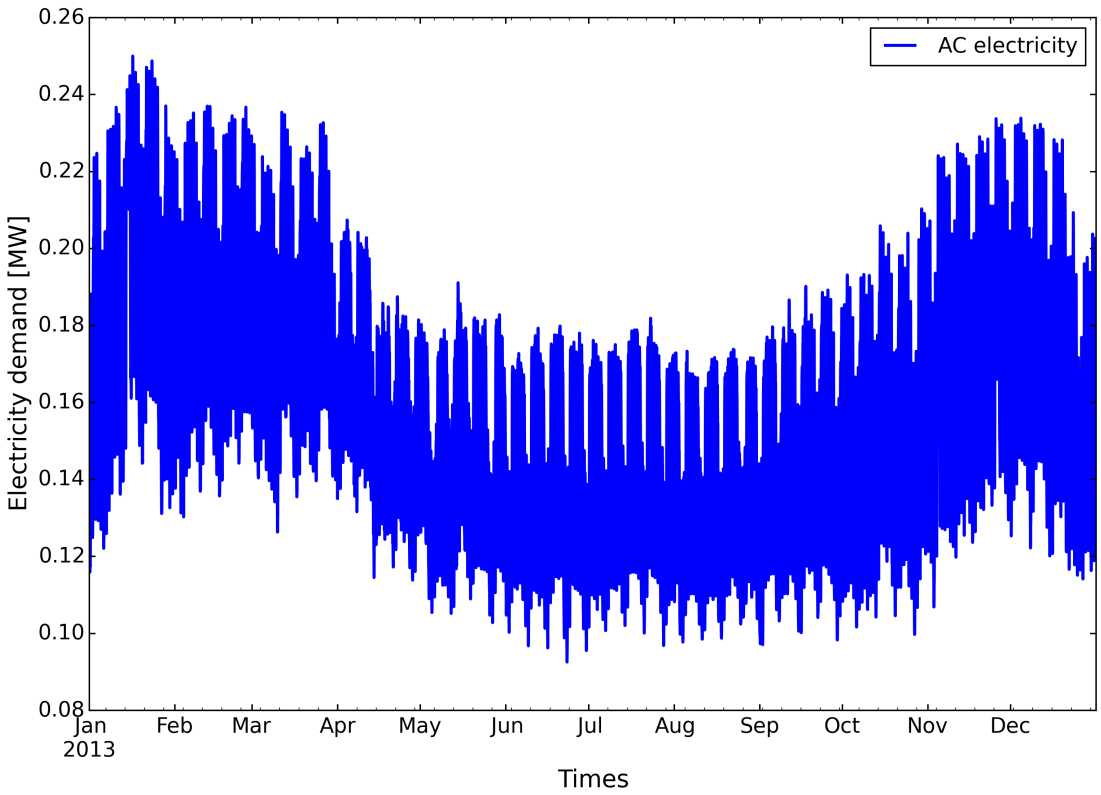
HEATS input and control

- Commodity: resources, demands and intermediaries
- Units: type of energy converters and storages
- Connections: originating unit, commodity and receiving unit
- Demands: demand profiles
- Resources: renewables and fossil fuels



Case study - electricity demand

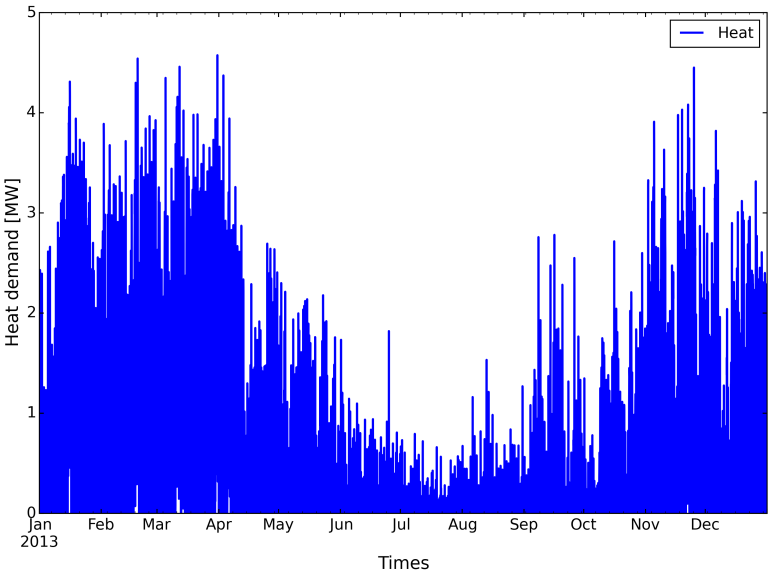
- Community of 335 domestic buildings in the North of Scotland
- Electricity demand profile from UK profile scaled to 335 properties
- Annual electricity demand 1480 MWh



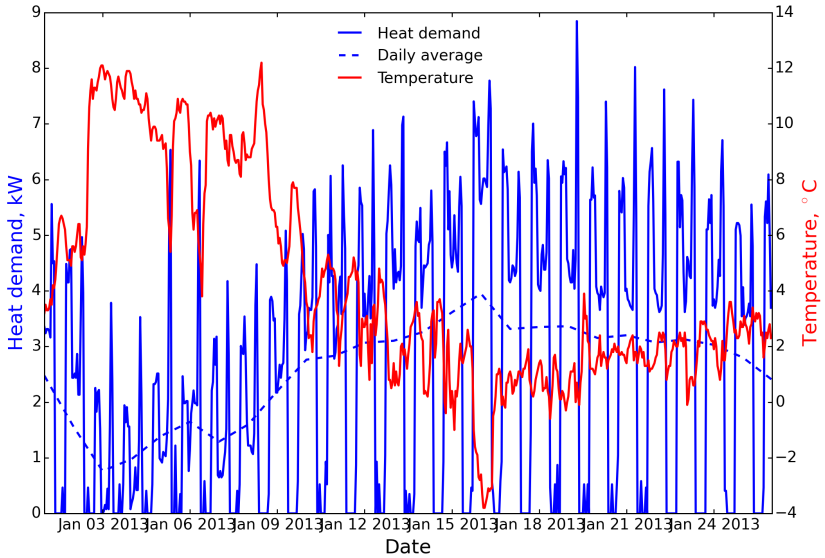
Data from National Grid and http://www.gridwatch.templar.co.uk

Case study - heat demand

- Heat demand for 335 domestic properties from temperature profile, UK average annual demand and a distribution of occupancy profiles
- Annual heat demand 4643 MWh



Total heat demand

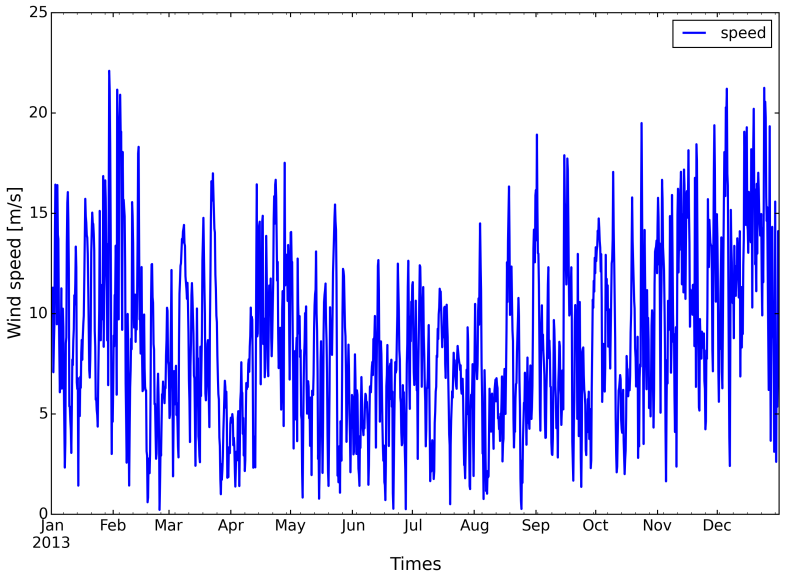


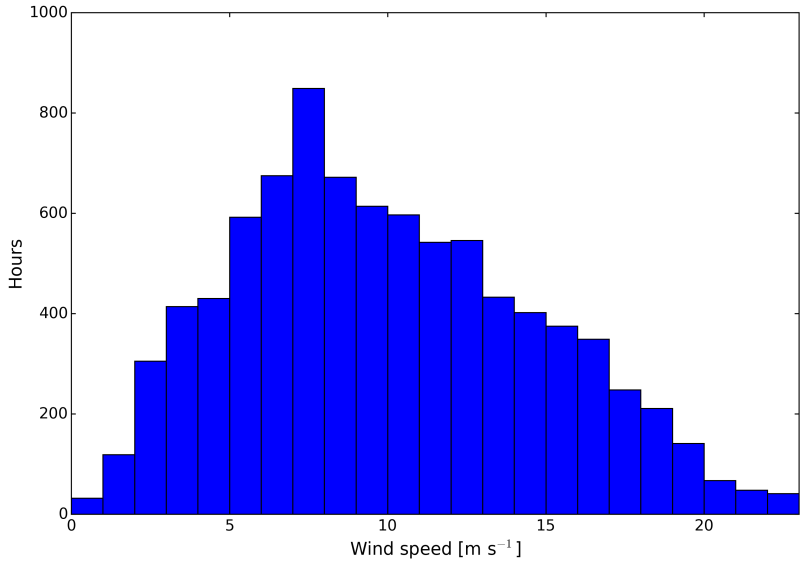
Single property demand for 3 winter weeks

Renaldi et al. Optimisation of Thermal Energy Storage Integration in a Residential Heating System, SusTEM 2015, Newcastle, UK, 2015, p. 131.

Case study - wind resource

- Wind speed at 10 metre hub height for Orkney
- Use power law to calculate wind speed at hub height (35m)





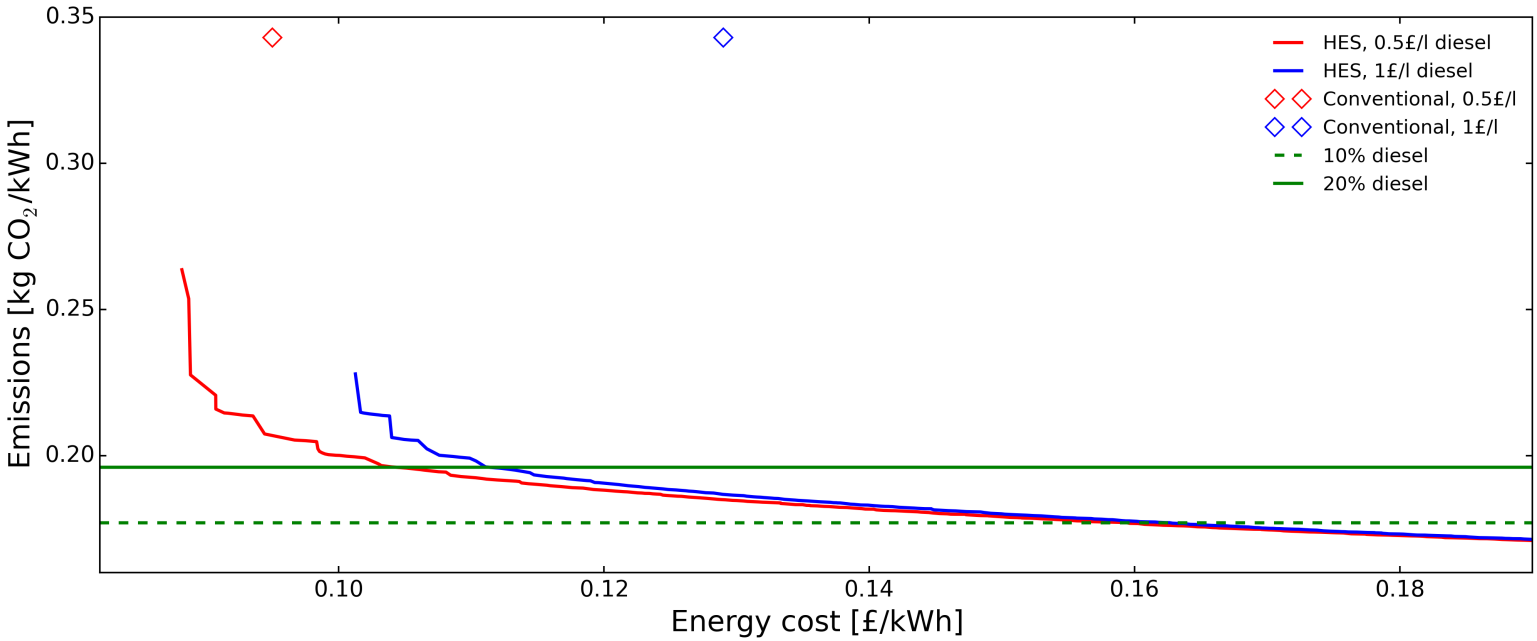
Energy system case studies

1. Electricity from diesel generators and heating from gas boilers
2. Hybrid electricity system and gas boilers
3. Hybrid electricity and heating system with backup

Case 1: fossil fuel electricity and heat

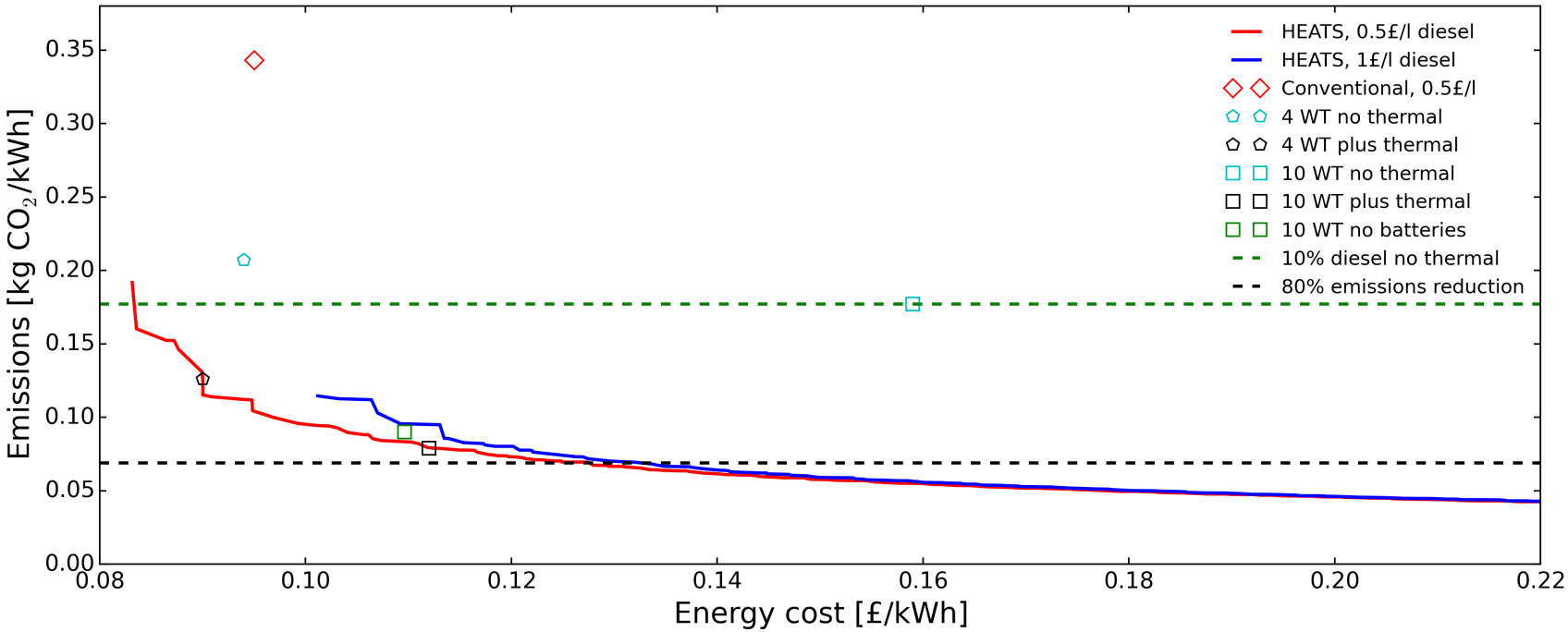
- Costs
  - Electricity cost 0.148 £ kWh^{-1} for a diesel cost of 0.5 £/l
  - Electricity cost 0.292 £ kWh^{-1} for a diesel cost of 1 £/l
  - Heating cost 0.078 £ kWh^{-1}
  - Combined energy costs 0.128 £ kWh^{-1} for a diesel cost of 1 £/l
- Emissions
  - 0.779 kg_{CO_2} kWh_{el}^{-1} or 1153 tons of CO_2
  - 0.208 kg_{CO_2} kWh_{th}^{-1} or 965 tons of CO_2
  - Total emissions of 0.343 kg_{CO_2} kWh^{-1} or 2118 tons of CO_2
- Strong dependence on fuel costs

Case 2: Hybrid electricity and fossil fuel heat



- Configuration for $\approx$ 20% diesel:
  - 6 wind turbines and 230 kWh of battery storage
  - Dumped renewable electricity 3516 MWh
- Configuration for $\approx$ 10% diesel:
  - 10 wind turbines and 1480 kWh of battery storage
  - Dumped renewable electricity 6441 MWh
- Same energy cost: 4 wind turbines and 150 kWh storage gives 0.207 kg CO_2 kWh^{-1} or 26% diesel contribution

Case 3: Full hybrid electricity and heat with backup



- Integration of electric and thermal loads improves the utilisation of the renewable resource
- Not all of the renewable electricity and heat is used
  - Integrate power-to-gas or liquid
  - Seasonal heat storage
  - Potential for PCM and thermochemical TES

Conclusion

- Deep decarbonisation is a significant challenge
- Combining different resources and demands can help to reduce the fossil fuel fraction
- Integration of electricity and heat (and transport) has large potential to increase the utilisation of the variable resource
- Future energy systems require the integration of electricity and heat with storage
- Thermal storage energy capacity is an order of magnitude cheaper and should be part of the energy system

Acknowledgements

Thanks to my students Jonathan Fallman, Renaldi and George Lavidas.

Questions?

Thank you for your attention!

HES equipment

- Vestas V27 wind turbine: hub height 35 m; rated power 225 kW; cut-in, rated and cut-out speed of 3.5, 14 and 25 m/s
- Perkins 175 kW diesel generator: hourly diesel consumption at rated capacity is 48 litres
- Battery storage at 600£ kWh^{-1}
- Mitsubishi Ecodan 8.5kW air source heat pump
- Gas boiler with 90% efficiency
- Domestic hot water storage tanks